QingKeV5 Microprocessor Manual

V1.0

Overview

QingKe V5 series microprocessors are self-developed 32-bit general-purpose MCU microprocessors based on standard RISC-V instruction set architecture. The series includes V5F. V5F supports RV32IMABCF instruction set and custom instruction set extensions XW. Supports single-cycle multiplication and hardware division, Hardware Prologue/Epilogue (HPE), Vector Table Free (VTF), streamlined 1-/2-wire debugging interface, and support for "WFE" instruction.

Features

Features	Description
ISA	RV32IMABCFX
Pipeline	7-9 levels
FPU	Supported
Branch prediction	Static branch prediction
Interrupt	Support a total of 256 interrupts including exceptions, and supports VTF
HPE	Support up to 8 levels of HPE
Physical Memory Protection (PMP)	Supported
Low-power consumption mode	Support Sleep and Deep sleep modes, and support WFI and WFE sleep methods
Extended Instruction Set	Supported
Debug	1/2-wire SDI, standard RISC-V debug

Chapter 1 Overview

QingKe V5 series microprocessors specific differences are detailed in Table 1-1.

Table 1-1 Overview of QingKe V5 microprocessor

Feature / Model	ISA	HPE number of levels	Interruptions nesting number of levels	VTF number of channels	Pipeline	Vector table mode	Extended Instruction (XW)	Number of memory protection areas
V5F	RV32IMAB CFX	8	8	4	7-9	Address/ Instruction	√	√

Note: OS task switching generally uses stack push, which are not limited in number of levels

1.1 Instruction Set

QingKe V5 series microprocessors follow the standard RISC-V Instruction Set Architecture (ISA). Detailed documentation of the standard can be found in the RISC-V International website. The RISC-V instruction set has a simple architecture and supports a modular design, allowing for flexible combinations based on different needs, and the V5 series supports the following instruction set extensions.

- RV32: 32-bit architecture, general-purpose register bit width of 32 bits
- I: Support integer operation, with 32 integer registers
- M: Support integer multiplication and division instructions
- A: Support atomic instructions
- C: Support 16-bit compression instruction
- B: Support bit manipulation instructions
- F: Support single-precision floating-point instructions
- XW: 16-bit compression instructions for self-extending byte and halfword operations

Note:

1: In order to further improve the code density, extend the XW subset, add the following compression instructions c.lbu/c.lhu/c.sb/c.sh/c.lbusp/c.lhusp/c.sbsp/c.shsp, use of which needs to be based on the MRS compiler or the toolchain it provides;

1.2 Register Set

The RV32I has 32 register sets from x0-x31. In the RV32, each register is 32 bits. Table 1-2 below lists the registers of RV32I and their descriptions.

Table 1-2 RV32I general-purpose registers

Register	ABI Name	Description	Storer
x0	zero	Hardcoded 0	-
x1	ra	Return address	Caller
x2	sp	Stack pointer	Callee
x3	gp	Global pointer	-
x4	tp	Thread pointer	-
x5-7	t0-2	Temporary register	Caller
x8	s0/fp	Save register/frame pointer	Callee
x9	s1	Save register	Callee
x10-11	a0-1	Function parameters/return values	Caller
x12-17	a2-7	Function parameters	Caller

x18-27	a2-11	Save register	Callee
X28-31	t3-6	Temporary register	Caller

The Caller attribute in the above table means that the called procedure does not save the register value, and the Callee attribute means that the called procedure saves the register.

The V5F model core supports the F instruction set and has a total of 32 floating-point registers, F0-F31, which are used to store data required for single-precision floating-point instructions. Table 1-3 below lists the floating-point registers and their descriptions.

Table 1-3 RISC-V5F registers

Register	ABI Name	Description	Storer
f0-7	ft0-7	Floating point temporary register	Caller
f8-9	fs0-1	Floating point save register	Callee
f10-11	fa0-1	Floating point function parameter /return values	Caller
f12-17	fa2-7	Floating point function parameter	Caller
f18-27	fs2-11	Floating point save register	Callee
f28-31	ft8-11	Floating point temporary register	Caller

The Caller attribute in the above table means that the called process does not save the value of this register, and the Callee attribute means that the called process saves this register.

1.3 Privilege Mode

The standard RISC-V architecture includes 3 privileged modes: Machine mode, Supervisor mode, and User mode, as shown in Table 1-3 below. The machine mode is a mandatory mode, and the other modes are optional modes. For details, you can refer to "The RISC-V Instruction Set Manual Volume II: Privileged Architecture", which can be downloaded for free from the RISC-V International website.

Table 1-4 RISC-V architecture privilege mode

Code	Name	Abbreviations
0b00	User Mode	U
0b01	Supervisor Model	S
0b10	Reserved	Reserved
0b11	Machine mode	M

QingKe V5 series microprocessors support two of these privileged modes.

- Machine mode

Machine mode has the highest authority, the program in this mode can access all the Control and Status Register (CSR), but also can access all the physical address area. The power-up default is in machine mode, when the execution of mret (Machine mode return instruction) returns, according to the CSR register mstatus (Machine mode status register) in the MPP bit, if MPP = 0b00, then exit the Machine mode into the User mode, MPP = 0b11, then continue to retain the Machine mode.

- User mode

User mode has the lowest privilege, and only limited CSR registers can be accessed in this mode. When an exception or interrupt occurs, the microprocessor goes from User mode to Machine mode to handle exceptions and interrupts.

1.4 CSR Register

A series of CSR registers are defined in the RISC-V architecture to control and record the operating state of the microprocessor. These CSRs can be extended by 4096 registers using an internal dedicated 12-bit address coding space. And use the high 2 CSR[11:10] to define the read/write permission of this register, 0b00, 0b01,

0b10 for read/write allowed and 0b11 for read only. Use the 2 bits CSR[9:8] to define the lowest privilege level that can access this register, and the value corresponds to the privilege mode defined in Table 1-4. The CSR registers implemented in the QingKe V5 microprocessor are detailed in Chapter 8.

Chapter 2 Exception

Exception mechanism, which is a mechanism to intercept and handle "unusual operation events". QingKe V5 series microprocessors are equipped with an exception response system that can handle up to 256 exceptions, including interrupts. When an exception or interruption occurs, the microprocessor can quickly respond and handle the exception and interruption events.

2.1 Exception Types

The hardware behavior of the microprocessor is the same whether an exception or an interrupt occurs. The microprocessor suspends the current program, moves to the exception or interrupt handler, and returns to the previously suspended program when processing is complete. Broadly speaking, interrupts are also part of exceptions. Whether exactly the current occurrence is an interrupt or an exception can be viewed through the Machine mode exception cause register mcause. The mcause[31] is the interrupt field, which is used to indicate whether the cause of the exception is an interrupt or an exception. mcause[31]=1 means interrupt, mcause[31]=0 means exception. mcause[30:0] is the exception code, which is used to indicate the specific cause of the exception or the interrupt number, as shown in the following table.

Table 2-1 V5 microprocessor exception codes

Interrupt	Exception codes	Synchronous / Asynchronous	Reason for exception
1	0-1	-	Reserved
1	2	Precise asynchronous	NMI interrupts
1	3-11	-	Reserved
1	12	Precise asynchronous	SysTick interrupts
1	13	-	Reserved
1	14	Synchronous	Software interrupts
1	15	-	Reserved
1	16-255	Precise asynchronous	External interrupt 16-255
0	0	Synchronous	Instruction address misalignment
0	1	Synchronous	Fetch command access error
0	2	Synchronous	Illegal instructions
0	3	Synchronous	Breakpoints
0	4	Synchronous	Load instruction access address misalignment
0	5	Synchronous	Load command access error
0	6	Synchronous	Store/AMO instruction access address misalignment
0	7	Non-precision asynchronous	Store/AMO command access error
0	8	Synchronous	Environment call in User mode
0	11	Synchronous	Environment call in Machine mode

'Synchronous' in the table means that an instruction can be located exactly where it is executed, such as an ebreak or ecall instruction, and each execution of that instruction will trigger an exception. 'Asynchronous' means that it is not possible to pinpoint an instruction, and the instruction PC value may be different each time an exception occurs. 'Precise asynchronous' means that after an exception occurs, it can precisely locate the boundary of an instruction, save all core state values at the time of the current exception, and resume the original instruction to continue executing the program after the exception is handled, such as an external interrupt. The 'non-precise asynchronous' refers to the inability to accurately locate the boundaries of a particular instruction, may be an instruction is interrupted halfway through the execution of the state, the

completion of the exception cannot be restored to the original normal operation of the program, such as memory access error. Access to memory takes time, the microprocessor access to memory is generally not always waiting for the end of the access, but to continue to execute the instruction, and then the access error exception, the microprocessor has already executed the subsequent instructions, cannot accurately locate or save the complete abnormal instruction before the register value.

2.2 Entering Exception

When the program is in the process of normal operation, if for some reason, triggered into an exception or interrupt. The hardware behavior of the microprocessor at this point can be summarized as follows.

(1) Suspend the current program flow and move to the execution of exception or interrupt handling functions. The entry base address and addressing mode of the exception or interrupt function are defined by the exception entry base address register mtvec. mtvec[31:2] defines the base address of the exception or interrupt function.

mtvec[1:0] defines the addressing mode of the handler function. when mtvec[0]=0, all exceptions and interrupts use a unified entry, i.e., when an exception or interrupt occurs, it turns to the mtvec[31:2] defines the base address to execute. When mtvec[0]=1, exceptions and interrupts use vector table mode, i.e., each exception and interrupt is numbered, and the address is offset according to interrupt number*4, and when an exception or interrupt occurs, it is shifted to the base address defined by mtvec[31:2] + interrupt number*4 Execution. The interrupt vector table holds an instruction to jump to the interrupt handler function, or it can be other instructions.

mtvec[1] defines whether an instruction or an address is stored in the entry address. When mtvec[1]=0, the exception entry address stores a jump instruction; when mtvec[1]=1, the exception entry address stores a jump address.

(2) Update CSR register

When an exception or interrupt is entered, the microprocessor automatically updates the relevant CSR registers, including the Machine mode exception cause register mcause, the Machine mode exception pointer register mepc, the Machine mode exception value register mtval, and the Machine mode status register mstatus.

- Update mcause

As mentioned before, after entering an exception or interrupt, its value reflects the current exception type or interrupt number, and the software can read this register value to check the cause of the exception or determine the source of the interrupt, as detailed in Table 2-1.

- Update mepc

The standard definition of the return address of the microprocessor after exiting an exception or interrupt is stored in mepc. So when an exception or interrupt occurs, the hardware automatically updates the mepc value to the current instruction PC value when the exception is encountered, or the next pre-executed instruction PC value before the interrupt. After the exception or interrupt is processed, the microprocessor uses its saved value as the return address to return to the location of the interrupt to continue execution.

However, it is worth noting that.

1. mepc is a readable and writable register, and the software can also modify the value for the purpose of modifying the location of the PC pointer running after the return.
2. When an interrupt occurs, i.e., when the exception cause register mcause[31]=1, the value of mepc is updated to the PC value of the next unexecuted instruction at the time of the interrupt.

And when an exception occurs, the value of mepc is updated to the instruction PC value of the current exception when the exception cause register mcause[31]=0. Therefore, when the exception returns, if you use the value of mepc to return directly, you will try to execute the exception instruction again, and then it is possible to enter the exception repeatedly. For some exceptions, the value of mepc can be changed to the value of the next unexecuted instruction before returning. For example, if we cause an exception due to ecall/ebreak, after handling the exception, since ecall/ebreak (c.ebreak is 2 bytes) is a 4-byte instruction, we only need the software to modify the value of mepc to mepc+4 (c.ebreak is mepc+2) and then return.

- Update mtval

When exceptions and interrupts are entered, the hardware will automatically update the value of mtval, which is the value that caused the exception. The value is typically.

1. If an exception is caused by a memory access, the hardware will store the address of the memory access at the time of the exception into mtval.
2. If the exception is caused by an illegal instruction, the hardware will store the instruction code of the instruction into mtval.
3. If the exception is caused by a hardware breakpoint, the hardware will store the PC value at the breakpoint into mtval.
4. For other exceptions, the hardware sets the value of mtval to 0, such as ebreak, the exception caused by ecall instruction.
5. When entering the interrupt, the hardware sets the value of mtval to 0.

- Update mstatus

Upon entering exceptions and interrupts, the hardware updates certain bits in mstatus.

1. MPIE is updated to the MIE value before entering the exception or interrupt, and MPIE is used to restore the MIE after the exception and interrupt are over.
2. MPP is updated to the privileged mode before entering exceptions and interrupts, and after the exceptions and interrupts are over, MPP is used to restore the previous privileged mode.
3. QingKe V5 microprocessor supports interrupt nesting in Machine mode. After entering exceptions and interrupts, the MIE is updated to a new value based on information such as the current nesting depth and nesting enable.

(3) Update microprocessor privilege mode

When exceptions and interrupts occur, the privileged mode of the microprocessor is updated to Machine mode.

2.3 Exception Handling Functions

Upon entering an exception or interrupt, the microprocessor executes the program from the address and mode defined by the mtvec register. When using unified entry, the microprocessor enters the interrupt from the base address defined by mtvec[31:2]. At this time, the exception and interrupt handling function can determine whether the cause is an exception or interrupt based on the value of mcause[31], and the type and cause of the exception or the corresponding interrupt can be judged by the exception code and handled accordingly.

When using the base address + interrupt number *4 for offset, the hardware automatically jumps to the vector table to get the entry address of the exception or interrupt function based on the interrupt number.

2.4 Exception Exit

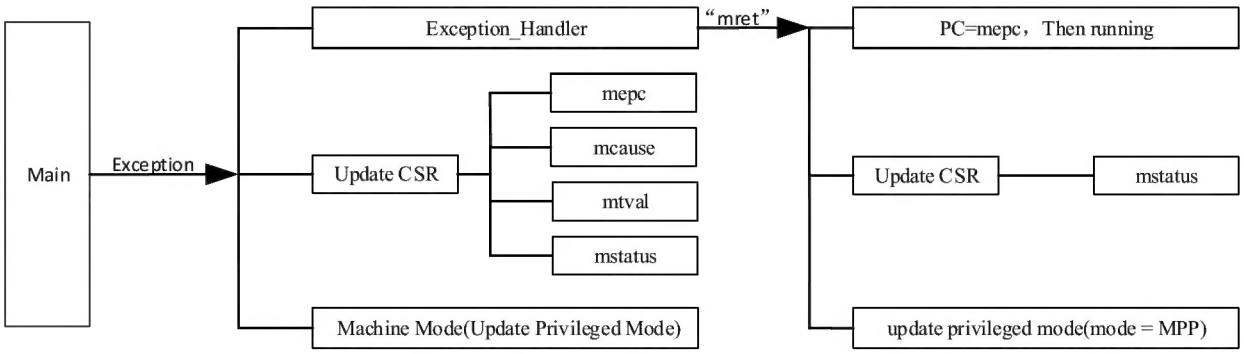
After the exception or interrupt handler is completed, it is necessary to exit from the service program. After

entering exceptions and interrupts, the microprocessor enters Machine mode from User mode, and the processing of exceptions and interrupts is also completed in Machine mode. When it is necessary to exit exceptions and interrupts, it is necessary to use the mret instruction to return. At this time, the microprocessor hardware will automatically perform the following operations.

- The PC pointer is restored to the value of CSR register mepc, i.e., execution starts at the instruction address saved by mepc. It is necessary to pay attention to the offset operation of mepc after the exception handling is completed.
- Update CSR register mstatus, MIE is restored to MPIE, and MPP is used to restore the privileged mode of the previous microprocessor.

The entire exception response process can be described by the following Figure 2-1.

Figure 2-1 Exception response process diagram



Chapter 3 PFIC and Interrupt Control

QingKe V5 microprocessor is designed with a Programmable Fast Interrupt Controller (PFIC) that can manage up to 256 interrupts including exceptions.

The first 32 of V5F are fixed as internal interrupts of the microprocessor, and the rest are external interrupts, i.e. the maximum number of external interrupts can be extended to 224. Its main features are as follows.

- 224 external interrupts, each interrupt request has independent trigger and mask control bits, with dedicated status bits
- Programmable multi-level interrupt nesting, maximum nesting depth 8 levels
- Unique fast interrupt access mechanism, Hardware Prologue/Epilogue (HPE) and recovery, maximum hardware stack pressing depth of 3 levels, no instruction overhead.
- Vector Table Free (VTF) interrupt response mechanism, 4-channel programmable direct access to interrupt vector addresses

The vector table of V5F interrupts and exceptions is shown in Table 3-1 below.

Table 3-1 V5F Exception and interrupt vector table

Number	Priority	Type	Name	Description
0	-6	Fixed	RESET	Reset interrupt
1	-	-	-	-
2	-5	Fixed	NMI	Non-maskable interrupt
3	-4	Fixed	HardFault	Exception interrupt
4	-	-	-	-
5	-3	Fixed	Ecall-M	Machine mode callback interrupt
6-7	-	-	-	-
8	-2	Fixed	Ecall-U	User mode callback interrupt
9	-1	Fixed	BreakPoint	Breakpoint callback interrupt
10-11	-	-	-	-
12	0	Programmable	SysTick0	System timer interrupt 0
13	1	Programmable	SysTick1	System timer interrupt 1
14	2	Programmable	SW	Software interrupt
15	-	-	-	-
16	3	Programmable	IPC_CH0	Inter-core communication interrupt 0
17	4	Programmable	IPC_CH1	Inter-core communication interrupt 1
18	5	Programmable	IPC_CH2	Inter-core communication interrupt 2
19	6	Programmable	IPC_CH3	Inter-core communication interrupt 3
20-27	-	-	-	-
28	7	Programmable	HSEM	Hardware semaphore interrupt
29-31	-	-	-	-
32-255	8-224	Programmable	External Interrupt	External interrupt 32-255

Note: The specific implementation of interrupts 16-31 may be different in different chip models, refer to the chip model manual for specific implementation.

3.1 PFIC Register Set

Table 3-2 PFIC Registers

Name	Access address	Access	Description	Reset value
PFIC_ISRx	0xE000E000 -0xE000E01C	RO	Interrupt enable status register x	0x00000000
PFIC_IPRx	0xE000E020 -0xE000E03C	RO	Interrupt pending status register x	0x00000000
PFIC_ITHRESDR	0xE000E040	RW	Interrupt priority threshold configuration register	0x00000000
PFIC_CFGR	0xE000E048	RW	Interrupt configuration register	0x00000000
PFIC_GISR	0xE000E04C	RO	Interrupt global status register	0x00000002
PFIC_VTFIDR	0xE000E050	RW	VTF interrupt ID configuration register	0x00000000
PFIC_VTFADDRRx	0xE000E060 -0xE000E06C	RW	VTF interrupt x offset address register	0x00000000
PFIC_IENRx	0xE000E100 -0xE000E11C	WO	Interrupt enable setting register x	0x00000000
PFIC_IRERx	0xE000E180 -0xE000E19C	WO	Interrupt enable clear register x	0x00000000
PFIC_IPSRx	0xE000E200 -0xE000E21C	WO	Interrupt pending setting register x	0x00000000
PFIC_IPRRx	0xE000E280 -0xE000E29C	WO	Interrupt pending clear register x	0x00000000
PFIC_IACTRx	0xE000E300 -0xE000E31C	RO	Interrupt activation status register x	0x00000000
PFIC_IPRIORx	0xE000E400 -0xE000E43C	RW	Interrupt priority configuration register	0x00000000
PFIC_EENR	0xE000EC80	RW	Event enable register	0xFFFFFFFF
PFIC_EPR	0xE000EC84	RW1Z	Event pending register	0x00000000
PFIC_EWUPR	0xE000EC88	RO	Event wake-up register	0x00000000
PFIC_SCTLR	0xE000ED10	RW	System control register	0x00000000

Note: 1. NMI, EXC, ECALL-M, ECALL-U, BREAKPOINT are always enabled by default.

2. ECALL-M, ECALL-U, and BREAKPOINT are a case of EXC.

3. NMI, EXC, ECALL-M, ECALL-U, BREAKPOINT support interrupt pending clear and setting operation, but not interrupt enable clear and setting operation.

Each register is described as follows:

Interrupt enable status and interrupt pending status registers (PFIC_ISR<0-7>/PFIC_IPR<0-7>)

Name	Access address	Access	Description	Reset value
PFIC_ISR0	0xE000E000	RO	Interrupt 0-31 enable status register, a total of 32 status bits [n], indicating #n interrupt enable status *Note: NMI and EXC are enabled*	0x0000032C

			by default	
PFIC_ISR1	0xE000E004	RO	Interrupt 32-63 enable status register, total 32 status bits	0x00000000
…	…	…	…	…
PFIC_ISR7	0xE000E01C	RO	Interrupt 224-255 enable status register, total 32 status bits	0x00000000
PFIC_IPR0	0xE000E020	RO	Interrupt 0-31 pending status register, a total of 32 status bits [n], indicating the pending status of interrupt #n	0x00000000
PFIC_IPR1	0xE000E024	RO	Interrupt 32-63 pending status registers, 32 status bits in total	0x00000000
…	…	…	…	…
PFIC_IPR7	0xE000E03C	RO	Interrupt 244-255 pending status register, 32 status bits in total	0x00000000

2 sets of registers are used to enable and de-enable the corresponding interrupts.

Interrupt enable setting and clear registers (PFIC_IENR<0-7>/PFIC_IRER<0-7>)

Name	Access address	Access	Description	Reset value
PFIC_IENR0	0xE000E100	WO	Interrupt 0-31 enable setting register, a total of 32 setting bits [n], for interrupt #n enable setting *Note: NMI and EXC are enabled by default*	0x00000000
PFIC_IENR1	0xE000E104	WO	Interrupt 32-63 enable setting register, total 32 setting bits	0x00000000
…	…	…	…	…
PFIC_IENR7	0xE000E11C	WO	Interrupt 224-255 enable setting register, total 32 setting bits	0x00000000
-	-	-	-	-
PFIC_IRER0	0xE000E180	WO	Interrupt 0-31 enable clear register, a total of 32 clear bits [n], for interrupt #n enable clear *Note: NMI and EXC cannot be operated*	0x00000000
PFIC_IRER1	0xE000E184	WO	Interrupt 32-63 enable clear register, total 32 clear bits	0x00000000
…	…	…	…	…
PFIC_IRER7	0xE000E19C	WO	Interrupt 244-255 enable clear register, total 32 clear bits	0x00000000

2 sets of registers are used to enable and de-enable the corresponding interrupts.

Note: When using registers to mask any interrupt or using CSR registers to mask global interrupts, add a 'fence.i' instruction to synchronize between core control state and interrupt enable state.

Interrupt pending setting and clear registers (PFIC_IPSR<0-7>/PFIC_IPRR<0-7>)

Name	Access address	Access	Description	Reset value
PFIC_IPSR0	0xE000E200	WO	Interrupt 0-31 pending setting register, 32 setting bits [n], for interrupt #n pending setting	0x00000000
PFIC_IPSR1	0xE000E204	WO	Interrupt 32-63 pending setup register, total 32 setup bits	0x00000000
…	…	…	…	…
PFIC_IPSR7	0xE000E21C	WO	Interrupt 224-255 pending setting register, 32 setting bits in total	0x00000000
-	-	-	-	-
PFIC_IPRR0	0xE000E280	WO	Interrupt 0-31 pending clear register, a total of 32 clear bits [n], for interrupt #n pending clear	0x00000000
PFIC_IPRR1	0xE000E284	WO	Interrupt 32-63 pending clear register, total 32 clear bits	0x00000000
…	…	…	…	…
PFIC_IPRR7	0xE000E29C	WO	Interrupt 244-255 pending clear register, total 32 clear bits	0x00000000

When the microprocessor enables an interrupt, it can be set directly through the interrupt pending register to trigger into the interrupt. Use the interrupt pending clear register to clear the pending trigger.

Interrupt activation status register (PFIC_IACTR<0-7>)

Name	Access address	Access	Description	Reset value
PFIC_IACTR0	0xE000E300	RO	Interrupt 0-31 activates the status register with 32 status bits [n], indicating that interrupt #n is being executed	0x00000000
PFIC_IACTR1	0xE000E304	RO	Interrupt 32-63 activation status registers, 32 status bits in total	0x00000000
…	…	…	…	…
PFIC_IACTR7	0xE000E31C	RO	Interrupt 224-255 activation status register, total 32 status bits	0x00000000

Each interrupt has an active status bit that is set up when the interrupt is entered and cleared by hardware when mret returns.

Interrupt priority and priority threshold registers (PFIC_IPRIOR<0-7>/PFIC_ITHRESDR)

Name	Access address	Access	Description	Reset value
PFIC_IPRIOR0	0xE000E400	RW	Interrupt 0 priority configuration. [7:4]: Priority control bits If the configuration is not nested, no preemption bit If nesting is configured, the	0x00

			preemption bit width is determined according to the csr.intsyscr.PMTCFG register. [3:0]: Reserved, fixed to 0 *Note: The smaller the priority value, the higher the priority. If the same preemption priority interrupt hangs at the same time, the interrupt with the higher priority will be executed first.*	
PFIC_IPRIOR1	0xE000E401	RW	Interrupt 1 priority setting, same function as PFIC_IPRIOR0	0x00
PFIC_IPRIOR2	0xE000E402	RW	Interrupt 2 priority setting, same function as PFIC_IPRIOR0	
…	…	…	…	…
PFIC_IPRIOR254	0xE000E4FE	RW	Interrupt 254 priority setting, same function as PFIC_IPRIOR0	0x00
PFIC_IPRIOR255	0xE000E4FF	RW	Interrupt 255 priority setting, same function as PFIC_IPRIOR0	0x00
-	-	-	-	-
PFIC_ITHRESDR	0xE000E040	RW	Interrupt priority threshold setting [31:8]: Reserved, fixed to 0 [7:4]: Priority threshold [3:0]: Reserved, fixed to 0 *Note: For interrupts with priority value ≥ threshold, the interrupt service function is not executed when a hang occurs, and when this register is 0, it means the threshold register is invalid.*	0x00

Interrupt configuration register (PFIC_CFGR)

Name	Access address	Access	Description	Reset value
PFIC_CFGR	0xE000E048	RW	Interrupt configuration register	0x00000000

Its bits are defined as:

Name	Access address	Access	Description	Reset value
[31:0]	SYSRST	WO	System reset when 0xBEEF0080 is written, other values are invalid.	0

Interrupt global status register (PFIC_GISR)

Name	Access address	Access	Description	Reset value

PFIC_GISR	0xE000E04C	RO	Interrupt global status register	0x00000000

Its folks are defined as.

Bit	Name	Access	Description	Reset value
[31:16]	Reserved	RO	Reserved	0
[15:14]	EXSTATE	RO	Core status register, used to get the operational status of the core: 00: Running; 01: Light sleep; 10: Deep sleep; 11: Deep sleep (locked).	0
13	LOCKSTA	RO	Whether the processor is currently in a locked state: 1: Locked state; 0: Non-locked state.	0
12	DBGMODE	RO	Whether the processor is currently in debug state: 1: Debug state; 0: Non-debug state.	0
11	GLOBLIE	RO	Global interrupt enable: 1: Enable interrupt; 0: Disable interrupt.	
10	Reserved	RO	Reserved	0
9	GPENDSTA	RO	Whether an interrupt is currently pending. 1: Yes; 0: No.	0
8	GACTSTA	RO	Whether an interrupt is currently being executed. 1: Yes; 0: No.	0
[7:0]	NESTSTA	RO	Current interrupt nesting status. [0x00]: No interrupts; [0x01]: Level 1 interrupts; [0x03]: Level 2 interrupt nesting; [0x07]: Level 3 interrupt nesting; [0x0F]: Level 4 interrupt nesting; [0x1F]: Level 5 interrupt nesting; [0x3F]: Level 6 interrupt nesting; [0x7F]: Level 7 interrupt nesting; [0xFF]: Level 8 interrupt nesting; Other: Reserved.	0

Offset address registers (PFIC_VTFADDRR<0-3>)

Name	Access address	Access	Description	Reset value
PFIC_VTFIDR	0xE000E050	RW	[31:24]: Number of VTF 3 [23:16]: Number of VTF 2 [15:8]: Number of VTF 1 [7:0]: Number of VTF 0	0x00000000
-	-	-	-	-

PFIC_VTFADDRR0	0xE000E060	RW	[31:1]: VTF interrupt 0 address, two-byte aligned [0]: 1: Enable table-free interrupt 0 channel 0: Disable	0xXXXXXXXX
PFIC_VTFADDRR1	0xE000E064	RW	[31:1]: VTF interrupt 1 address, two-byte aligned [0]: 1: Enable table-free interrupt 1 channel 0: Disable	0xXXXXXXXX
PFIC_VTFADDRR2	0xE000E068	RW	[31:1]: VTF interrupt 2 address, two-byte aligned [0]: 1: Enable table-free interrupt 2 channel 0: Disable	0xXXXXXXXX
PFIC_VTFADDRR3	0xE000E06C	RW	[31:1]: VTF interrupt 3 address, two-byte aligned [0]: 1: Enable table-free interrupt 3 channel 0: Disable	0xXXXXXXXX

Event enable register (PFIC_EENR)

Name	Access address	Access	Description	Reset value
PFIC_EENR	0xE000EC80	RW	Event enable register	0x00000000

Some chips support it, see the chip manual for the implementation, and its folks are defined as:

Name	Access address	Access	Description	Reset value
[31:0]	EVENTEN	RW	31#-0# event wakeup enable: 1: Allow the corresponding event to wake up the kernel during sleep; 0: Block the corresponding event and do not allow waking up the core when this event occurs. Up to 32 event sources are supported, of which 0-7 is level triggered (high active) and 8-31 is pulse triggered: 0#: Core pause request; 1#: Core interrupt request; 7#-2#: Reserved; 8#: Core entry interrupt; 9#: Core exit interrupt;	0xFFFFFFFF

			10#: A new interrupt is pending; (For shared interrupts, it is not distinguished whether the interrupt is routed to the local core.) 11#: Core sends event; (Local core sends events) 12#: Core receive events;(Other core sends events) 13#: The system receives events;(system-configured events such as GPIO rollover events…) 31#-14#: Reserved.	

Event pending register (PFIC_EPR)

Name	Access address	Access	Description	Reset value
PFIC_EPR	0xE000EC84	RW	Event pending register	0x00000000

Some chips support it, see the chip manual for the implementation, and its folks are defined as:

Name	Access address	Access	Description	Reset value
[31:8]	EVENT_PEND	RW1Z	31#-8# Event pending status, write 1 to clear: 1: The corresponding event occurs without being processed; 0: The corresponding event does not occur.	0
[7:0]	EVENT_PEND	RO	7#-0# Event pending status, not clearable: 1: The corresponding event occurred without being processed; 0: The corresponding event did not occur.	0

Event wakeup register (PFIC_EWUPR)

Name	Access address	Access	Description	Reset value
PFIC_EENR	0xE000EC84	RO	Event wakeup register	0x00000000

Some chips support it, see the chip manual for the implementation, and its folks are defined as:

Name	Access address	Access	Description	Reset value
[31:0]	EVENT_WUP	RO	31#-0# event wake-up registers: 1: The corresponding event wakes up the core from sleep; 0: The corresponding event is not the event that wakes up the core this time.	0

System control register (PFIC_SCTLR)

Name	Access address	Access	Description	Reset value
PFIC_SCTLR	0xE000ED10	RW	System control register	0x00000000

Each of them is defined as follows.

Bit	Name	Access	Description	Reset value
31	SYSRESET	WO	System reset, auto clear 0. Write 1 is valid, write 0 is invalid.	0
[30:24]	Reserved	RO	Reserved	0
[23:16]	HART_ID	RO	Core ID register, used to get the core ID of the core reading this register: 1: this core is C1; 0: this core is C0.	0
[15:6]	Reserved	RO	Reserved	0
5	SETEVENT	WO	Set the event to wake up the WFE case.	0
4	SEVONPEND	RW	When an event occurs or interrupts a pending state, the system can be woken up from after the WFE instruction, or if the WFE instruction is not executed, the system will be woken up immediately after the next execution of the instruction. 1: Enabled events and all interrupts (Including unenabled interrupts) can wake up the system. 0: Only enabled events and enabled interrupts can wake up the system.	0
3	WFITOWFE	RW	Execute the WFI command as if it were a WFE. 1: Treat the subsequent WFI instruction as a WFE instruction. 0: No effect.	0
2	SLEEPDEEP	RW	Low power mode of the control system. 1: deepsleep 0: sleep	0
1	SLEEPONEXIT	RW	System status after control leaves the interrupt service program. 1: The system enters low-power mode. 0: The system enters the main program.	0
0	Reserved	RO	Reserved	0

3.2 Interrupt-related CSR Registers

In addition, the following CSR registers also have a significant impact on the processing of interrupts.

Interrupt system control register (intsyscr)

Name	CSR Address	Access	Description	Reset value
intsyscr	0x804	URW	Interrupt system control register	0x0000E002

Its folks are defined as:

Bit	Name	Access	Description	Reset value
31	LOCK	URO	0: This register can be read and written in user mode; 1: This register can only be read and written in machine mode.	0
[30:6]	Reserved	URO	Reserved	0x380
5	GIHWSTKNEN	URW1	Global interrupt and hardware stack shutdown are enabled. *Note: This bit is often used in real-time operating systems. When the context is switched during an interrupt, setting this bit can turn off the global interrupt and push the hardware stack. When the context switch is completed and the interrupt returns, the hardware will automatically clear this bit.*	0
4	Reserved	URO	Reserved	0
[3:2]	PMTCFG	URW	Configuration of priority preemption bits: 00: The number of preemption bits is 0; 01: The number of preemption bits is 1; 10: The number of preemption bits is 2; 11: The number of preemption bits is 3;	0
1	INESTEN	URW	The interrupt nesting function is enabled, and the fixed value is 1: 0: Disable; 1: Enable. *Note: The actual nesting level is controlled by NEST_LVL in CSR 0xBC1;*	1
0	HWSTKEN	URW	Hardware stack enable: 0: Hardware stack pressing function is disabled; 1: Hardware stack pressing function is enabled.	0

Machine mode exception base address register (mtvec)

Name	CSR Address	Access	Description	Reset value
mtvec	0x305	MRW	Exception base address register	0x00000000

Its folks are defined as.

Bit	Name	Access	Description	Reset value
[31:2]	BASEADDR	MRW	Interrupt vector table base address, where bits [9:2] are fixed to 0.	0
1	MODE1	MRO	Interrupt vector table recognition mode:	0

			0: Identify by jump instruction, with limited scope, and support non-jump instruction; 1: Identify by absolute address, support full range, but must jump.	
0	MODE0	MRW	Interrupt or exception entry address mode selection. 0: Use of the uniform entry address. 1: Address offset based on interrupt number *4.	0

For MCUs with V5 series microprocessors, MODE0 is configured to be 1 by default in the startup file, and the entries for exceptions or interrupts are offset according to the interrupt number *4. Note that the V5F microprocessor stores a jump instruction at the vector table, which is configured as an absolute address in the default startup file.

Microprocessor configuration register (corecfgr)

Name	CSR Address	Access	Description	Reset value
corecfgr	0xBC0	MRW	Microprocessor configuration register	0x12370000

Its folks are defined as.

Bit	Name	Access	Description	Reset value
[31:28]	FADD_CLKDIV	MRW	Floating-point plus instruction division factor, default value is 1, that is, floating-point plus instruction frequency is the dominant frequency of 2 division.	0x1
[27:24]	FMUL_CLKDIV	MRW	Floating-point plus instruction division factor, default value is 2, that is, floating-point plus instruction frequency is the dominant frequency of 3 division.	0x2
[23:20]	FMAC_CLKDIV	MRW	Floating-point plus instruction division factor, default value is 3, that is, floating-point plus instruction frequency is the dominant frequency of 4 division.	0x3
[19:16]	FDIV_CLKDIV	MRW	Floating-point plus instruction division factor, default value is 7, that is, floating-point plus instruction frequency is the dominant frequency of 8 division.	0x7
15	NLP_EN	MRW	The next line of the branch prediction function is enabled: 0: Disable; 1: Enabled.	0
14	GHR_EN	MRW	Global history register function enable: 0: Branch global history register disable; 1: Branch global history register enable.	0
10	LSU_DUAL	MRW	Memory instruction parallel transmit	0

			enable, when set to 1, allows the transmitter unit to transmit memory instructions in parallel to increase the speed of memory instruction transmission.	
9	Reserved	MRO	Reserved	11b
7	CSTA_FAULT_IE	MRW	Core status error interrupt enable: 0: On status error, no NMI interrupt is generated; 1: On status error, NMI interrupt is generated.	0
6	Reserved	MRO	Reserved	0
5	IE_REMAP_EN	MRW	MIE register mapping enable: 0: CSR address 0x800 is a read-only register and the return value is the value of MSTATUS; 1: Bits 3 and 7 of CSR address 0x800 are mapped to bit MIE of the MSTATUS register and bit MPIE of the MSTATUS register, respectively.	0
[4:0]	Reserved	MRO	Reserved	0

Floating-point arithmetic instructions are multi-cycle instructions, for different types of floating-point instructions, the maximum running frequency constraints check each chip manual. Depending on the processor's operating frequency, the user needs to configure the floating-point arithmetic crossover coefficients so that the frequency after crossover is not higher than the maximum operating frequency shown in the table above.

fxxx_- freq（max） ≥ Core main frequency / fxxx_- clkdiv

Interrupt nested control register (inestcr)

Name	CSR Address	Access	Description	Reset value
inestcr	0xBC1	MRW	Interrupt nested control register	0x00000000

Its folks are defined as.

Bit	Name	Access	Description	Reset value
31	LSU_NMI_STA	MRW	The access unit generates a non-maskable interrupt flag (usually a write bus return error) and a write 1 reset.	0
30	NEST_OV	MRW	Interrupt/exception nested overflow flag bit, write 1 to clear: 0: Interrupt did not overflow; 1: Interrupt overflow flag. *Note: Interrupt overflow will only occur when executing secondary interrupt service function to generate instruction exception or NMI interrupt. At this time,*	0

			the exception and NMI interrupt enter normally, but the CPU stack overflows, so you cannot exit from this exception and NMI interrupt.	
[29:12]	Reserved	MRO	Reserved	0
[11:8]	NEST_STA	MRO	[0x00]: No interrupts; [0x01]: Level 1 interrupts; [0x03]: Level 2 interrupt nesting; [0x07]: Level 3 interrupt nesting; [0x0F]: Level 4 interrupt nesting; [0x1F]: Level 5 interrupt nesting; [0x3F]: Level 6 interrupt nesting; [0x7F]: Level 7 interrupt nesting; [0xFF]: Level 8 interrupt nesting; Other: Reserved.	0
[7:3]	Reserved	MRO	Reserved	0
[2:0]	NEST_LVL	MRW	Maximum nesting level: 000: Prohibit nesting, (Disable nesting function); 001: Allow 2-level nesting; 010: Allow 3-level nesting; 011: Allow 4-level nesting; 100: Allow 5-level nesting; 101: Allow 6-level nesting; 110: Allow 7-level nesting; 111: Allow 8-level nesting.	0

User mode global interrupt enable register (gintenr)

Name	CSR Address	Access	Description	Reset value
gintenr	0x800	URW	Global interrupt enable register	0x00000000

This register is used to control the enable and mask of global interrupt. The enable and mask of global interrupt in machine mode can be controlled by the MIE and MPIE bits in mstatus, but this register cannot be operated in user mode. The global interrupt enable register gintenr is the mapping of MIE and MPIE in mstatus, and can be used to set and clear MIE and MPIE by operating gintenr in user mode. Each of them is defined as:

Bit	Name	Access	Description	Reset value
31	SD	RO	Used to mark whether a floating-point instruction is in a dirty state.	0
[30:15]	Reserved	URO	Reserved	0
[14:13]	FS	RO	Floating-point instruction set state that allows single-precision floating-point instructions (F) to execute when the value is not zero: 00: OFF; 01: Initial;	0

			10: Clean; 11: Dirty.	
[12:11]	MPP	URO	Enter privileged mode before interruption.	0
[10:8]	Reserved	URO	Reserved	0
7	MPIE	URW	When 0xBC0(CSR) bit5 is enabled, this bit can be read and written in user mode.	0
[6:4]	Reserved	URO	Reserved	0
3	MIE	URW	When 0xBC0(CSR) bit5 is enabled, this bit can be read and written in user mode.	0
[1:0]	Reserved	URO	Reserved	0

3.3 Interrupt Nesting

In conjunction with the interrupt configuration register PFIC_CFGR and the interrupt priority register PFIC_IPRIOR, nesting of interrupts can be allowed to occur. Enable nesting in the interrupt configuration register (Nesting is turned on by default for V5 series microprocessors) and configure the priority of the corresponding interrupt. The smaller the priority value, the higher the priority. The smaller the value of the preemption bit, the higher the preemption priority. If there are interrupts hanging at the same time under the same preemption priority, the microprocessor responds to the interrupt with the lower priority value (higher priority) first.

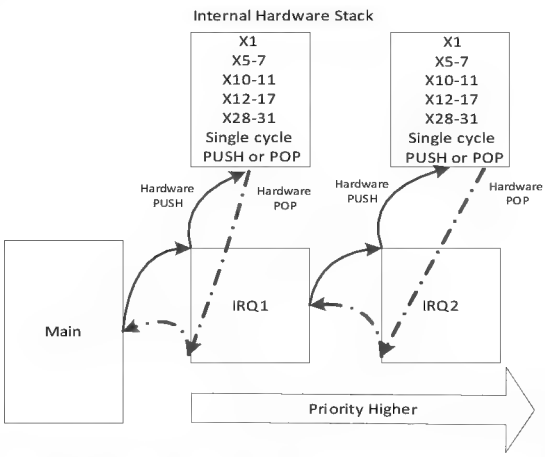
3.4 Hardware Prologue/Epilogue (HPE)

When an exception or interrupt occurs, the microprocessor stops the current program flow and shifts to the execution of the exception or interrupt handling function, the site of the current program flow needs to be saved. After the exception or interrupt returns, it is necessary to restore the site and continue the execution of the stopped program flow. For V5 series microprocessors, the "site" here refers to all the Caller Saved registers in Table 1-2.

The V5 series microprocessors support hardware single-cycle automatic saving of 16 of the integer Caller Saved registers to an internal stack area that is not visible to the user. When an exception or interrupt returns, the hardware single cycle automatically restores the data from the internal stack area to the 16 integer registers. HPE supports nesting up to 2 levels deep.

A schematic of the microprocessor pressure stack is shown in the following figure.

Figure 3-1 Schematic diagram of pressure stack



Note: 1. Interrupt functions using the HPE need to be compiled using MRS or its provided toolchain and the interrupt function needs to be declared with __attribute__((interrupt("WCH-Interrupt-fast"))).

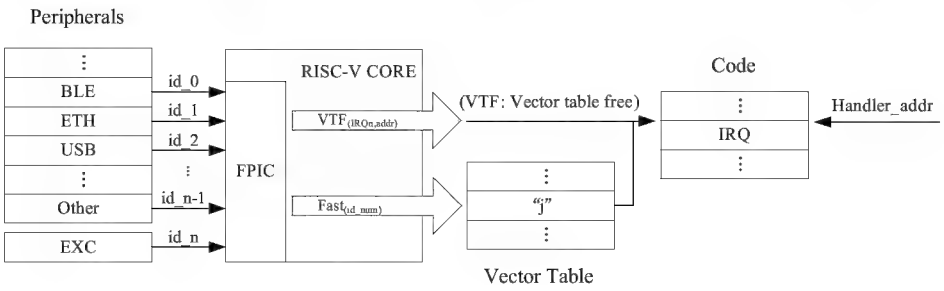
2. The interrupt function using stack push is declared by __attribute__((interrupt())).

3.5 Vector Table Free (VTF)

The Programmable Fast Interrupt Controller (PFIC) provides 4 VTF channels, i.e., direct access to the interrupt function entry without going through the interrupt vector table lookup process.

The VTF channel can be enabled by writing its interrupt number, interrupt service function base address and offset address into the corresponding PFIC controller register while configuring an interrupt function normally. The PFIC response process for fast and table-free interrupts is shown in Figure 3-2 below.

Figure 3-2 Schematic diagram of programmable fast interrupt controller



Chapter 4 Physical Memory Protection (PMP)

In order to improve the security of the system, the physical memory protection (PMP) module is designed according to RISC-V architecture standard for the V5 series microprocessors of highland barley. Access rights management of up to 4 physical region is supported. Permissions include read (R), write (W) and execute (X) attributes, and the length of the protected area can be set to 4 bytes at least. PMP module always takes effect in user mode, but it can take effect optionally by locking (L) attribute in machine mode.

If the access violates the current permission limit, it will trigger an abnormal interrupt. The PMP module includes four groups of 8-bit configuration registers (One group of 32-bit) and four groups of address registers, all of which need to be accessed in machine mode by CSR instruction.

Note: The number of protected areas supported by PMP in different models of microprocessors may be different, and the number supported by pmpcfg and pmpaddr registers is also different. See Table 1-1 for details.

4.1 PMP Register Set

The list of CSR registers supported by PMP module of V5 microprocessor is shown in Table 4-1 below.

Table 4-1 PMP module register set

Name	CSR address	Access	Description	Reset value
pmpcfg0	0x3A0	MRW	PMP configuration register 0	0x00000000
pmpaddr0	0x3B0	MRW	PMP address register 0	0xXXXXXXXX
pmpaddr1	0x3B1	MRW	PMP address register 1	0xXXXXXXXX
pmpaddr2	0x3B2	MRW	PMP address register 2	0xXXXXXXXX
pmpaddr3	0x3B3	MRW	PMP address register 3	0xXXXXXXXX

4.2 pmp<i>cfg Register

pmpcfg is the configuration register of PMP unit, and each register contains four 8-bit pmpcfg fields, corresponding to the configuration of four regions, and pmpcfg represents the configuration value of region i. Its format is shown in the following table 4-2.

Table 4-2 pmpcfg0 register

31 24	23 16	15 8	7 0	
pmp3cfg	pmp2cfg	pmp1cfg	pmp0cfg	pmpcfg0

pmpcfg is used to configure area i, and its bit definition is described in the following table 4-3.

Table 4-3 pmp<i>cfg register

Bit	Name	Description
7	L	Locking is enabled and can be unlocked in machine mode. 0: Not locked; 1: Lock the relevant register.
6	IC_Str	When the addresses match, the instruction cache policy is executed, and the policy value corresponds to the CACHE_PMP_OVR register.
5	-	Reserved
[4:3]	A	Address alignment and protection area range selection. 00: OFF (PMP off) 01: TOR (Top alignment protection)

		10: NA4 (Fixed four-byte protection) 11: NAPOT ($2^{(G+2)}$ Byte protection, G≥1)
2	X	Executable attribute. 0: No execute permission; 1: Execute permission.
1	W	Writeable attribute. 0: No write permission 1: Write permission.
0	R	Readable attribute 0: No read permission 1: Read permission.

4.3 pmpaddr<i> Register

The pmpaddr register is used to configure the address of area I. The standard definition is under RV32 architecture, which is the encoding of the upper 32 bits of a 34-bit physical address, and its format is shown in the following table 4-4. The whole physical address space of V5 microprocessor is 4G, so the upper two bits of this register are not used.

Table 4-4 pmpaddr<i> register

31	0
address[33:2]	

When NAPOT is selected, the low bit of the address register is also used to indicate the size of the current protection area, as shown in the following table, where 'y' is a bit of the register.

Table 4-5 Relationship table between PMP configuration and address register and protected area

pmpaddr	pmpcfg.A	Matching base address and size
yyyy…yyyy	NA4	With 'yy…yyyy00' as the base address, the 4-byte area is protected.
yyyy…yyy0	NAPOT	With 'yy…yyy000' as the base address, the 8-byte area is protected.
yyyy…yy01	NAPOT	With 'yy…yy0000' as the base address, the 16-byte area is protected.
yyyy…y011	NAPOT	With 'yy…y00000' as the base address, the 32-byte area is protected.
…	…	…
yyy01…111	NAPOT	With 'y0…000000' as the base address, the 2^{31}-byte area is protected.
yy011…111	NAPOT	Protect the entire 2^{32}-byte area.

4.4 Protection Mechanism

X/W/R in pmpcfg is used to set the protection authority of area I, and violation of relevant authority will cause corresponding exception:

(1) When trying to fetch instructions in the PMP area without execution authority, it will cause an instruction fetch access error exception (mcause=1).

(2) When trying to write data in the PMP area without write permission, it will cause an error exception (mcause=7) in the store instruction access.

(3) When trying to read data in the PMP area without read permission, it will cause an abnormal memory access error (mcause=5) for the load instruction.

A in pmpcfg is used to set the protection range and address alignment of region i, and to protect the memory of A_ADDR ≤ region < i > < B_ADDR (both A_ADDR and B_ADDR are required to be aligned in 4 bytes):

(1) If B _ ADDR–A_ADDR = = 2^2, NA4 mode is adopted;

(2) If B _ ADDR - A_ADDR = = $2^{(G+2)}$, G≥1, and a _ addr is $2^{(G+2)}$, the NAPOT method is adopted;

(3) Otherwise, the TOP mode is adopted.

Table 4-6 PMP address matching methods

A value	Name	Description
0b00	OFF	No area to protect
0b01	TOR	Top Aligned Area Protection. Under pmp<i>cfg, $pmpaddr_{i-1}$≤ region<i> <$pmpaddr_i$; $pmpaddr_{i-1}$ = A_ADDR >> 2; $pmpaddr_i$ = B_ADDR >> 2. *Note: If area 0 of PMP is configured as TOR mode (i=0), the lower boundary of the protection area is 0 address, i.e. 0 ≤ addr < pmpaddr0, all within the matching range.*
0b10	NA4	Fixed 4-byte area protection. pmp<i>cfg under pmpaddri as the starting address of the 4-byte pmpaddri = A_ADDR>>2.
0b11	NAPOT	Protect the $2^{(G+2)}$ region with G ≥ 1, when A_ADDR is $2^{(G+2)}$ aligned. pmpaddri = ((A_ADDR|($2^{(G+2)}$-1)) &~(1<<G+1))>>2.

The L bit in pmp<i>cfg is used to lock the PMP entry. After locking, the configuration register pmp<i>cfg and the address register pmpaddr<i> will not be able to be modified. If A in pmp<i>cfg is set to TOR mode, pmpaddr<i-1> will also not be modified. when L is set, the X/W/R permissions defined in pmp<i>cfg are also valid for machine mode, and when L is cleared, X/W/R is only valid for user mode, and L is cleared only after system reset.

QingKe V5 series microprocessors support protection of multiple zones. When the same operation matches multiple zones at the same time, the zone with the smaller number is matched first.

Chapter 5 System Timer (SysTick)

QingKe V5 series microprocessor is designed with a 32-bit or 64-bit counter (SysTick) inside. Its clock source is the system clock or its 8-frequency division. It can provide time base, timing and measuring time for real-time operating system.

Table 5-1 V5F SysTick register list

Name	Access address	Description	Reset value
STK_SR	0xE000F004	System counter status register	0x00000000
STK_CTLR	0xE000F080	System counter control register	0x00000000
STK_CNT	0xE000F088	System counter count register	0x00000000
STK_CMP	0xE000F090	System counter compare register	0x00000000

Each register is described in detail as follows.

System counter status register (STK_SR)

Bit	Name	Access	Description	Reset value
31	Reserved	RO	Reserved	0
[30:1]	Reserved	RO	Reserved	0
1	STK_ISR1	RW	Systick interrupt flag: 1: There is an unprocessed interrupt request for the timer; 0: There is no interrupt request for the timer.	0
0	Reserved	RO	Reserved	0

System counter control register (STK_CTLR)

Bit	Name	Access	Description	Reset value
[31:7]	Reserved	RO	Reserved	0
6	CID	RW	Counter assignment core register, which is used to configure the counter to generate interrupt requests to the specified core, and is automatically updated to the core ID of the operation when the counter enable is configured to be valid. *Note: See specific chip for details.*	0
5	Reserved	RO	Reserved	0
4	MODE	RW	Counting mode: 1: Count down; 0: Count up.	0
3	STRE	RW	Automatic reload count enable bit: 1: Count from 0 again after counting up to the comparison value, and count from the comparison value again after counting down to 0; 0: Continue counting up/down.	0
2	STCLK	RW	Counter clock source selection bit:	0

			1: HCLK as time base; 0: HCLK/8 as time base.	
1	STIE	RW	Counter interrupt enable control bits: 1: Enable counter interrupt; 0: Disable counter interrupt.	0
0	STE	RW	System counter enable control bit. 1: Enable system counter STK; 0: Disable the system counter STK and the counter stops counting.	0

System counter count register (STK_CNT)

Bit	Name	Access	Description	Reset value
[31:0]	CNT_1	RW	Systick counting register, which can accumulate/subtract and reload automatically according to the configuration after counting is enabled.	0

System counter compare register (STK_CMP)

Bit	Name	Access	Description	Reset value
[31:0]	CMP_1	RW	Systick comparison register, used for comparison during upward counting and automatic reloading during downward counting.	0

Chapter 6 Processor Low-power Settings

QingKe V5 series microprocessors support sleep state via WFI (Wait For Interrupt) instruction to achieve low static power consumption. Together with PFIC's system control register (PFIC_SCTLR), various Sleep modes and WFE instructions can be implemented.

6.1 Enter Sleep

QingKe V5 series microprocessors can go to sleep in 2 ways, Wait For Interrupt (WFI) and Wait For Event (WFE). The WFI method means that the microprocessor goes to sleep, waits for an interrupt to wake up, and then wakes up to the corresponding interrupt to execute. The WFE method means that the microprocessor goes to sleep, waits for an event to wake up, and wakes up to continue executing the previously stopped program flow.

The standard RISC-V supports WFI instruction, and the WFI command can be executed directly to enter sleep by WFI method. For the WFE method, the WFITOWFE bit in the system control register PFIC_SCTLR is used to control the subsequent WFI commands as WFE processing to achieve the WFE method to enter sleep.

The depth of sleep is controlled according to the SLEEPDEEP bit in PFIC_SCTLR.

- If the SLEEPDEEP in PFIC_SCTLR register is cleared to zero, the microprocessor enters Sleep mode and the internal unit clock is allowed to be turned off except for SysTick and part of the wake-up logic.
- If SLEEPDEEP in the PFIC_SCTLR register is set, the microprocessor enters Deep sleep mode and all cell clocks are allowed to be turned off.

When the microprocessor is in Debug mode, it is not possible to enter any kind of Sleep mode.

6.2 Sleep Wakeup

QingKe V5 series microprocessors can be woken up after sleep due to WFI and WFE in the following ways.

- After the WFI method goes to sleep, it can be awakened by

(1) The microprocessor can be woken up by the interrupt source responded by the interrupt controller. After waking up, the microprocessor executes the interrupt function first.

(2) Enter Sleep mode, debug request can make the microprocessor wake up and enter deep sleep, debug request cannot wake up the microprocessor.

- After the WFE method goes to sleep, the microprocessor can be woken up by the following.

(1) Internal or external events, when there is no need to configure the interrupt controller, wake up and continue to execute the program.

(2) If the SEVONPEND bit in PFIC_SCTLR is configured, the interrupt controller does not enable the interrupt under, but when a new interrupt pending signal is generated (the previously generated pending signal does not take effect), it can also make the microprocessor wake up, and the corresponding interrupt pending flag needs to be cleared manually after waking up.

(3) Enter Sleep mode debug request can make the microprocessor wake up and enter deep sleep, debug request cannot wake up the microprocessor.

In addition, the state of the microprocessor after wake-up can be controlled by configuring the SLEEPONEXIT bit in PFIC_SCTLR.

- SLEEPONEXIT is set and the last level interrupt return instruction (mret) will trigger the WFI mode sleep.

- SLEEPONEXIT is cleared with no effect.

Various MCU products equipped with V5 series microprocessors can adopt different sleep modes, turn off different peripherals and clocks, implement different power management policies and wake-up methods according to different configurations of PFIC_SCTLR, and realize various low-power modes.

Chapter 7 Debug Support

QingKe V5 series microprocessors include a hardware debug module that supports complex debugging operations. When the microprocessor is suspended, the debug module can access the microprocessor's GPRs, CSRs, Memory, external devices, etc. through abstract commands, program buffer deployment instructions, etc. The debug module can suspend and resume the microprocessor's operation.

The debug module follows the RISC-V External Debug Support Version0.13.2 specification, detailed documentation can be downloaded from RISC-V International website.

7.1 Debug Module

The debug module inside the microprocessor, capable of performing debug operations issued by the debug host, includes.

- Access to registers through the debug interface
- Reset, suspend and resume the microprocessor through the debug interface
- Read and write memory, instruction registers and external devices through the debug interface
- Deploy multiple arbitrary instructions through the debug interface
- Set software breakpoints through the debug interface
- Set hardware breakpoints through the debug interface
- Support abstract command auto-execution
- Support single-step debugging

Note: V5F does not support hardware breakpoints support instruction address and data address matching.

The internal registers of the debugging module use a 7-bit address code, and the following registers are implemented inside QingKe V5 series microprocessors.

Table 7-1 Debug module register List

Name	Access address	Description
data0	0x04	Data register 0, can be used for temporary storage of data
data1	0x05	Data register 1, can be used for temporary storage of data
dmcontrol	0x10	Debug module control register
dmstatus	0x11	Debug module status register
hartinfo	0x12	Microprocessor status register
abstractcs	0x16	Abstract command status register
command	0x17	Abstract command register
abstractauto	0x18	Abstract command auto-execution
progbuf0-7	0x20-0x27	Instruction cache registers 0-7
haltsum0	0x40	Pause status register
capabi	0x7c	Debugger interface register
config	0x7d	Debugger configuration register
config_pre	0x7e	Debugger pre-configuration registers
dcsr	0x7b0	Debug control and status register
dpc	0x7b1	Debug PC address register

The debug host can control the microprocessor's suspend, resume, reset, etc. by configuring the dmcontrol

register. The RISC-V standard defines three types of abstract commands: access register, fast access, and access memory. QingKe V5 microprocessor only supports register access, other models support register and memory access, but not fast access. Access to registers (GPRs, CSRs) and continuous access to memory can be realized by abstract commands.

The debug module implements 8 instruction cache registers progbuf0-7, and the debug host can cache multiple instructions (which can be compressed instructions) to the buffer, and can choose to continue executing the instructions in the instruction cache registers after executing the abstract command, or execute the cached instructions directly. Note that the last instruction in the progbufs needs to be an "ebreak" or "c.ebreak" instruction. Access to storage, peripherals, etc. is also possible through abstract commands and instructions cached in the progbufs.

Each register is described in detail as follows.

Data register 0 (data0)

Bit	Name	Access	Description	Reset Value
[31:0]	data0	RW	Data register 0, used for temporary storage of data	0

Data register 1 (data1)

Bit	Name	Access	Description	Reset Value
[31:0]	data1	RW	Data register 1, used for temporary storage of data	0

Debug module control register (dmcontrol)

This register controls the pause, reset, and resume of the microprocessor. Debug host write data to the corresponding field to achieve pause (haltreq), reset (ndmreset), resume (resumereq). You describe into the following.

Bit	Name	Access	Description	Reset Value
31	haltreq	WO	Pause the selected microprocessor, controlled by hartsel. 0: Clear the pause request 1: Send a pause request	0
30	resumereq	W1	Restore the selected microprocessor, controlled by hartsel. 0: Invalid 1: Restore the current microprocessor *Note: Write 1 is valid and the hardware is cleared after the microprocessor is recovered*	0
29	Reserved	RO	Reserved	0
28	ackhavereset	W1	0: Invalid 1: Clear the haverest status bit of the microprocessor	0
[27:18]	Reserved	RO	Reserved	0
[17:16]	hartsel	RW	Microprocessor selection register, fixed value 0.	0
[15:2]	Reserve	R0	Reserve	0
1	ndmreset	RW	0: Clear reset 1: Reset the entire system other than the debug	0

			module	
0	dmactive	RW	0: Reset debug module 1: Debug module works properly	0

Debug module status register (dmstatus)

This register is used to indicate the status of the debug module and is a read-only register with the following description of each bit.

Bit	Name	Access	Description	Reset Value
[31:23]	Reserved	RO	Reserved	0
22	impebreak	RO	Fixed value, a value of 1 means that an ebreak instruction is implied after progbuf.	1
[21:20]	Reserved	RO	Reserved	0
19	allhavereset	RO	0: Invalid 1: Microprocessor reset	0
18	anyhavereset	RO	0: Invalid 1: Microprocessor reset	0
17	allresumeack	RO	0: Invalid 1: Microprocessor reset	0
16	anyresumeack	RO	0: Invalid 1: Microprocessor reset	0
15	allnoexit	RO	The selected microprocessor does not exist and is controlled by hartsel 0: Microprocessor does not exist 1: Microprocessor is optional	0
14	anynoexit	RO	The selected microprocessor does not exist and is controlled by hartsel 0: Microprocessor does not exist 1: Microprocessor is optional	0
13	allavail	RO	0: Invalid 1: Microprocessor is not available	0
12	anyavail	RO	0: Invalid 1: Microprocessor is not available	0
11	allrunning	RO	0: Invalid 1: Microprocessor is running	0
10	anyrunning	RO	0: Invalid 1: Microprocessor is running	0
9	allhalted	RO	0: Invalid 1: Microprocessor is in suspension	0
8	anyhalted	RO	0: Invalid 1: Microprocessor out of suspension	0
7	authenticated	RO	0: Authentication is required before using the debug module 1: The debugging module has been certified	0x1
[6:4]	Reserved	RO	Reserved	0
[3:0]	version	RO	Debugging system support architecture version	0x2

			0010: V0.13	

Microprocessor status register (hartinfo)

This register is used to provide information about the microprocessor to the debug host and is a read-only register with each bit described as follows.

Bit	Name	Access	Description	Reset Value
[31:24]	Reserved	RO	Reserved	0
[23:20]	nscratch	RO	Number of dscratch registers supported	0x3
[19:17]	Reserved	RO	Reserved	0
16	dataaccess	RO	0: Data register is mapped to CSR address 1: Data register is mapped to memory address	0x1
[15:12]	datasize	RO	Number of data registers	0x2
[11:0]	dataaddr	RO	The offset address of the data register data0, whose base address is 0xe0000000, is subject to specific reading.	0xXXX

Abstract command control and status registers (abstractcs)

This register is used to indicate the execution of the abstract command. The debug host can read this register to know whether the last abstract command is executed or not, and can check whether an error is generated during the execution of the abstract command and the type of the error, which is described in detail as follows.

Bit	Name	Access	Description	Reset Value
[31:29]	Reserved	RO	Reserved	0
[28:24]	progbufsize	RO	Indicates the number of program buffer program cache registers	0x8
[23:13]	Reserved	RO	Reserved	0
12	busy	RO	0: No abstract command is executing 1: There are abstract commands being executed *Note: After execution, the hardware is cleared.*	0
11	Reserved	RO	Reserved	0
[10:8]	cmder	RW	Abstract command error type 000: No error 001: Abstract command execution to write to command, abstractcs, abstractauto registers or read and write to data and progbuf registers 010: Does not support current abstract command 011: Execution of abstract command with exception 100: The microprocessor is not suspended or unavailable and cannot execute abstract commands 101: Bus error 110: Parity bit error during communication 111: Other errors *Note: For bit writing 1 is used to clear the zero.*	0
[7:4]	Reserved	RO	Reserved	0
[3:0]	datacount	RO	Number of data registers	0x2

Abstract command register(command)

Debugging host can access GPRs, CSRs registers and memory by writing different configuration values into the abstract command register.

When accessing the registers, the command register bits are defined as follows.

Bit	Name	Access	Description	Reset Value
[31:24]	cmdtype	WO	Abstract command type 0: Access register; 1: Quick access (not supported); 2: Access to memory.	0
23	Reserved	WO	Reserved	0
[22:20]	aarsize	WO	Access register data bit width 000: 8-bit 001: 16-bit 010: 32-bit 011: 64-bit (not supported) 100: 128-bit (not supported) *Note: When accessing floating-point registers FPRs, only 32-bit access is supported.*	0
19	aarpostincrement	WO	0: No effect 1: Automatically increase the value of regno after accessing the register	0
18	postexec	WO	0: No effect 1 : Execute the abstract command and then execute the command in progbuf	0
17	transfer	WO	0: Do not execute the operation specified by write 1: Execute the manipulation specified by write	0
16	write	WO	0: Copy data from the specified register to data0 1: Copy data from data0 register to the specified register	0
[15:0]	regno	WO	Specify access registers 0x0000-0x0fff are CSRs 0x1000-0x101f are GPRs 0x1020-0x103f are FPRs	0

When accessing the memory of, the bits in the command register are defined as follows:

Bit	Name	Access	Description	Reset Value
[31:24]	cmdtype	WO	Abstract command type 0: Access register; 1: Fast access (not supported); 2: Access memory.	0
23	aamvirtual	WO	0: Access physical address; 1: Access virtual address.	0
[22:20]	aamsize	WO	Access memory data bit width 000: 8-bit; 001: 16-bit;	0

			010: 32-bit; 011: 64-bit (not supported); 100: 128-bit (not supported);	
19	aampostincrement	WO	0: No influence; 1: After accessing the memory successfully, increase the address stored in the data1 register by the number of bytes corresponding to the bit width configured by aamsize. Aamsize=0, accessed by byte, data1 plus 1. Aamsize=1, accessed by half-word, data1 plus 2. aamsize=2, accessed by bit, data1 plus 4.	0
18	postexec	WO	0: No influence; 1: Execute the command in progbuf after executing the abstract command.	0
17	Reserve	RO	Reserved	0
16	write	WO	0: Read data from the address specified by data1 to data0 1: Write data in data0 to the address specified by data1.	0
[15:14]	target-specific	WO	Definition of reading and writing mode Write: 00, 01: Write directly to the memory; 10: After the data in data0 is OR with the data bits in the memory, the result is written into the memory (Only word access is supported). 11: After summing the data in data0 with the data bits in the memory, write the result into the memory (Only word access is supported). Read: 00, 01, 10, 11: Read directly from the memory.	0
[13:0]	Reserve	RO	Reserved	0

Abstract command automatic execution register (abstractauto)

This register is used to configure the debugging module. When reading and writing progbufx and datax of the debugging module, the abstract command can be executed again. The description of this register is as follows:

Bit	Name	Access	Description	Reset Value
[31:16]	autoexecprogbuf	RW	If a bit is set, the corresponding reading and writing of progbufx will cause the abstract command in the command register to be executed again. *Note: V5 series is designed with 8 progbufs, corresponding to bits [23:16].*	0
[15:12]	Reserved	RO	Reserved	0
[11:0]	autoexecdata	RW	If a bit is set to 1, the corresponding reading and writing of the datax register will cause the abstract	0

			command in the Command register to be executed again. *Note: V5 series is designed with 2 data registers, corresponding to bits [1:0].*	

Instruction cache register (progbufx)

This register is used to store arbitrary instructions and deploy corresponding operations, including eight. Note that one "ebreak" instruction is hidden after progbuf.

Bit	Name	Access	Description	Reset Value
[31:0]	progbuf	RW	Instruction encoding for cache operations, which may include compression instructions	0

Pause status register (haltsum0)

This register is used to indicate whether the microprocessor is suspended or not. Each bit indicates the suspended status of a microprocessor, and when there is only one core, only the lowest bit of this register is used to indicate it.

Bit	Name	Access	Description	Reset Value
[31:2]	Reserved	RO	Reserved	0
1	haltsum0	RO	haltsum0 V5F core suspend state 0: Microprocessor operates normally 1: Microprocessor stop	0
0	Reserved	RO	Reserved	0

Debug interface register (capabi)

This register is used to obtain information such as protocol and frequency supported by debugging.

Bit	Name	Access	Description	Reset Value
[31:28]	swd_version	RO	1-wire interface version information	1
[27:24]	twd_version	RO	2-wire interface version information	1
[23:18]	SWD_FREQ	RO	1-wire interface sampling clock frequency, 25MHz	25
[17:16]	dmi_info	RO	Debugger support 1/2-wire communication information 00: Dual line only 01: Single line only 11: Single/dual line support	0x3
15	SWD&TWD	RO	Flag bit for both 1/2-wire communication support 0: Only 1/2-wire communication is supported 1: Both 1/2-wire communication is supported	1
[14:11]	Reserved	RO	Reserved	0
10	output_cap	RO	Debugger allows data output	1
[9:0]	Reserved	RO	Reserved	0

Debug interface configuration register (config)

This register is used to configure the debugger 1/2-wire mode, output enable, communication rate and other information. This register does not support direct writing. It is necessary to write the value to the config_pre

register first, and then write the configuration password and configuration bit mask to this register. After this register value is written and takes effect.

Bit	Name	Access	Description	Reset Value
[31:16]	config_key	WO	Write configuration password register, write operation takes effect when 0x5aa5 is written	0
15	swdmd	RW	1/2-wire selection register, write 1 to synchronize swdmd_pre register value 1: 2-wire communication; 0: 1-wire communication.	1
[14:11]	Reserved	RO	Reserved	0
10	outen	RW	Debugger output enable, set 1 to allow output data, write 1 to synchronize outen_pre register value 0: Output mask; 1: Output enable.	0
[9:2]	Reserved	RO	Reserved	0
[1:0]	psc1x	RW	Synchronized outen_pre register value when writing 11b to the 1-wire communication code element rate selection register 00: 1-wire code element base frequency is 8M; 01: 1-wire code element base frequency is 4M; 10: 1-wire code element base frequency is 25M; 11: 1-wire code element base frequency is 12.5M.	1

Note: 10b and 11b of psc1x bits are unit symbol rates configured differently in different chips and are related to capabi.SWD_FREQ values. See the specific chip manual for details.

Debug interface pre-configuration register (config_pre)

This register is used to pre-configure the debugger single/two-wire mode, output enable, communication rate and other information. When the configuration password is written to this register, the write operation takes effect. The config_pre register and config register need to be configured continuously, and other registers cannot be operated during this period.

Bit	Name	Access	Description	Reset Value
[31:16]	config_key	WO	Write the configuration password register, write 0x5aa5 when the write operation takes effect, after the configuration password is correct, read this register to read 0x5aa5 that the pre-configuration register is written successfully, allowing to write the configuration register, otherwise read this register value is 0, cannot configure the config register.	0
15	swdmd_pre	RW	1/2-wire pre-select register	1
[14;11]	Reserved	RO	Reserved	0
10	outen_pre	RW	Debugger output pre-enable	0
[9:2]	Reserved	RO	Reserved	0
[1:0]	psc1x_pre	RW	1-wire communication symbol rate preselection register	1

In addition to the above-mentioned registers of the debug module, the debug function also involves some CSR registers, mainly the debug control and status register dcsr and the debug instruction pointer dpc, which are described in detail as follows.

Debug control and status register (dcsr)

Bit	Name	Access	Description	Reset Value
[31:28]	xdebugver	DRO	0000: External debugging is not supported 0100: Support standard external debugging 1111: External debugging is supported, but does not meet the specification	0x4
[27:16]	Reserved	DRO	Reserved	0
15	ebreakm	DRW	0: The ebreak command in machine mode behaves as described in the privilege file 1: The ebreak command in machine mode can enter debug mode	0
[14:13]	Reserved	DRO	Reserved	0
12	ebreaku	DRW	0: The ebreak command in user mode behaves as described in the privilege file 1: The ebreak command in user mode can enter debug mode	0
11	stepie	DRW	0: Interrupts are disabled under single-step debugging 1: Enable interrupts under single-step debugging	0
10	Reserved	DRO	Reserved	0
9	stoptime	DRW	0: System timer running in Debug mode 1: System timer stop in Debug mode	0
[8:6]	cause	DRO	Reasons for entering debugging 001: Entering debugging in the form of ebreak command (priority 3) 010: Entering debugging in the form of trigger module (priority 4, the highest) 011: Entering debugging in the form of pause request (priority 1) 100: debugging in the form of single-step debugging (priority 0, the lowest) 101: enter debug mode directly after microprocessor reset (priority 2) Others: Reserved	0
[5:4]	Reserved	DRO	Reserved	0
2	step	DRW	0: Turn off single-step debugging 1: Enable single-step debugging	0
3	nmi_pend	DRO	Non-maskable interrupt pending status	0
[1:0]	prv	DRW	Privilege mode 00: User mode 01: Supervisor mode (not supported) 10: Reserved	0

			11: Machine mode *Note: Record the privileged mode when entering debug mode, the debugger can modify this value to modify the privileged mode when exiting debug*	

Debug mode program pointer (dpc)

This register is used to store the address of the next instruction to be executed after the microprocessor enters debug mode, and its value is updated with different rules depending on the reason for entering debug. dpc register is described in detail as follows.

Bit	Name	Access	Description	Reset Value
[31:0]	dpc	DRW	Instruction address	0

The rules for updating the registers are shown in the following table.

Enter the debugging method	dpc Update rules
ebreak	Address of the Ebreak instruction
single step	Instruction address of the next instruction of the current instruction
trigger module	Temporarily not supported
halt request	Address of the next instruction to be executed when entering Debug

7.2 Debug Interface

Different from the standard JTAG interface defined by RISC-V, QingKe V5 series microprocessor adopts 1-wire/2-wire serial debug interface and follows WCH debug interface protocol V1.0. The debug interface is responsible for the communication between the debug host and the debug module, and realizes the read/write operation of the debug host to the debug module registers. WCH designed WCH_Link and open source its schematic and program binary files, which can be used for debugging all microprocessors of RISC-V architecture.

Refer to WCH Debug Protocol Manual for specific debug interface protocols.

Chapter 8 CSR Register List

The RISC-V architecture defines a number of Control and Status Registers (CSRs) for controlling and recording the operating status of the microprocessor. Some of the CSRs have been introduced in the previous section, and this chapter will detail the CSR registers implemented in the QingKe V5 series microprocessors.

8.1 CSR Register List

Table 8-1 List of Microprocessor CSR Registers

Type	Name	CSR Address	Access	Description
RISC-V Standard CSR	mvendorid	0xF11	MRO	Chip Manufacturer ID Register
	marchid	0xF12	MRO	Architecture number register
	mimpid	0xF13	MRO	Hardware implementation numbering register
	mhartid	0xF14	MRO	Core ID register
	mstatus	0x300	MRW	Status register
	misa	0x301	MRW	Hardware instruction set register
	mtvec	0x305	MRW	Exception base address register
	mcount_inhibit	0x320	MRW	Counter mask register
	mscratch	0x340	MRW	Machine mode staging register
	mepc	0x341	MRW	Exception program pointer register
	mcause	0x342	MRW	Exception cause register
	mtval	0x343	MRW	Exception value register
	pmpcfg<i>	0x3A0+i	MRW	PMP configuration register
	pmpaddr<i>	0x3B0+i	MRW	PMP address register
	tselect	0x7A0	MRW	Debug trigger selection register
	tdata1	0x7A1	MRW	Debug trigger data register 1
	tdata2	0x7A2	MRW	Debug trigger data register 2
	tinfo	0x7A4	MRO	Trigger information register
	dcsr	0x7B0	DRW	Debug control and status registers
	dpc	0x7B1	DRW	Debug mode program pointer register
	dscratch0	0x7B2	DRW	Debug mode staging register 0
	dscratch1	0x7B3	DRW	Debug mode staging register 1
	dbgmcu_0	0x7C0	MRW	Debug Register 0
	mcycle	0xB00	MRW	Machine cycle counter register
	minstret	0xB02	MRW	Machine instruction counter register
	ucycle	0xC00	RO	User mode cycle counter register
	uinstret	0xC02	RO	User mode instruction counter register
	fflags	0x001	RW	Floating point accumulation exception flag register
	frm	0x002	RW	Floating point rounding mode register
	fcsr	0x003	RW	Floating point control and status register
	cache_strtg_ctlr	0xBC2	MRW	Cache policy control register
	cache_pmp_ovr	0xBC3	MRW	Cache policy PMP override register
	hw_popdm_addr	0xBC4	MRW	Hardware stack address register
	memary_cfgr	0xBC5	MRW	Memory configuration register
	tcm_rrduty_cfgr	0xBC6	MRW	TCM priority access duration configuration register
	mie	0xBC8	MRW	Machine interrupt register
	opcache_ctlr	0xBD0	WO	Cache operation register
	meminfo	0xFC0	MRO	Memory information register
Vendor defined CSR	gintenr	0x800	URW	Global interrupt enable register
	intsyscr	0x804	URW	Interrupt system control register
	corecfgr	0xBC0	MRW	Microprocessor configuration register

	inestcr	0xBC1	MRW	Interrupt nested control register

8.2 RISC-V Standard CSR Registers

Chip Manufacturer ID Register (marchid)

Bit	Name	Access	Description	Reset Value
[31:0]	mvendorid	MRO	Chip Manufacturer ID, fixed value 0.	0

Architecture number register (marchid)

This register is a read-only register to indicate the current microprocessor hardware architecture number, which is mainly composed of vendor code, architecture code, series code, and version code. Each of them is defined as follows.

Bit	Name	Access	Description	Reset Value
31	Reserved	MRO	Reserved	1
[30:26]	Vender0	MRO	Manufacturer code 0 Fixed to the letter 'W' code	0x17
[25:21]	Vender1	MRO	Manufacturer code1 Fixed to the letter 'C' code	0x03
[20:16]	Vender2	MRO	Manufacturer code 2 Fixed to the letter 'H' code	0x08
15	Reserved	MRO	Reserved	1
[14:10]	Arch	MRO	Architecture code RISC-V architecture is fixed to the letter 'V' code	0x16
[9:5]	Serial	MRO	Series code QingKe V5 series, fixed to the number '3'	0x03
[4:0]	Verision	MRO	Version code Can be the version 'A', 'B', 'C' and other letters of the code	x

The manufacturer number and version number are alphabetic, and the series number is numeric. The coding table of letters is shown in the following table.

Table 8-1 Alphabetic Mapping Table

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

Hardware implementation numbering register (mimpid)

This register is mainly composed of vendor codes, each of which is defined as follows.

Bit	Name	Access	Description	Reset Value
31	Reserved	MRO	Reserved	1
[30:26]	Vender0	MRO	Manufacturer code 0 Fixed to the letter 'W' code	0x17
[25:21]	Vender1	MRO	Manufacturer code1 Fixed to the letter 'C' code	0x03
[20:16]	Vender2	MRO	Manufacturer code 2 Fixed to the letter 'H' code	0x08

15	Reserved	MRO	Reserved	1
[14:8]	Reserved	MRO	Reserved	0
[7:4]	Minor	MRO	Subversion number	0xX

Core ID register (mhartid)

Bit	Name	Access	Description	Reset Value
[31:0]	mhartid	MRO	Core ID, indicating the core ID number of this core in the chip architecture.	0

Machine mode status register (mstatus)

This register has been partially described in the previous section, and its folks are positioned as follows.

Bit	Name	Access	Description	Reset Value
31	SD	MRO	Used to mark whether a floating-point instruction is in a dirty state.	0
[30:13]	Reserved	MRO	Reserved	0
[14:13]	FS	MRW	Floating-point instruction set state that allows single-precision floating-point instructions(F) to execute when the value is not zero: 00: OFF; 01: Initial; 10: Clean; 11: Dirty.	0
[12:11]	MPP	MRW	Privileged mode before entering break	0
[10:8]	Reserved	MRO	Reserved	0
7	MPIE	MRW	Interrupt enable state before entering interrupt	0
[6:4]	Reserved	MRO	Reserved	0
3	MIE	MRW	Machine mode interrupt enable	0
[2:0]	Reserved	MRO	Reserved	0

The MPP field is used to save the privileged mode before entering the exception or interrupt, and is used to restore the privileged mode after exiting the exception or interrupt. MIE is the global interrupt enable bit, and when entering the exception or interrupt, the value of MPIE is updated to the value of MIE, and it should be noted that in the QingKe V5 series microprocessors, MIE will not be updated to 0 before the last level of nested interrupts to ensure that the interrupt nesting in Machine mode continues to be executed. When an exception or interrupt is exited, the microprocessor reverts to the Machine mode saved by MPP and the MIE is restored to the MPIE value.

QingKe V5 microprocessor supports Machine mode and User mode, if you need to make the microprocessor only work in Machine mode, you can set the MPP to 0x3 in the initialization of the boot file, that is, after returning, it will always remain in Machine mode.

Hardware instruction set register (misa)

This register is used to indicate the architecture of the microprocessor and the supported instruction set extensions, each of which is described as follows.

Bit	Name	Access	Description	Reset Value

[31:30]	MXL	MRO	Machine basic integer bit width and basic instruction bit width information, 32-bit wide kernel, fixed value is 1.	1
[29:26]	Reserved	MRO	Reserved	0
[25:0]	Extensions	MRO	Instruction set extensions	x

The MXL is used to indicate the word length of the microprocessor, QingKe V5 are 32-bit microprocessors, the domain is fixed to 1. Extensions are used to indicate that the microprocessor supports extended instruction set details, each indicates a class of extensions, its detailed description is shown in the following table.

Table 8-2 Instruction Set Extension Details

Bit	Name	Description
0	A	Atomic extension
1	B	Tentatively reserved for Bit-Manipulation extension
2	C	Compressed extension
3	D	Double-precision floating-point extension
4	E	RV32E base ISA
5	F	Single-precision floating-point extension
6	G	Additional standard extensions present
7	H	Hypervisor extension
8	I	RV32I/64I/128I base ISA
9	J	Tentatively reserved for Dynamically Translated Languages extension
10	K	Reserved
11	L	Tentatively reserved for Decimal Floating-Point extension
12	M	Integer Multiply/Divide extension
13	N	User-level interrupts supported
14	O	Reserved
15	P	Tentatively reserved for Packed-SIMD extension
16	Q	Quad-precision floating-point extension
17	R	Reserved
18	S	Supervisor mode implemented
19	T	Tentatively reserved for Transactional Memory extension
20	U	User mode implemented
21	V	Tentatively reserved for Vector extension
22	W	Reserved
23	X	Non-standard extensions present
24	Y	Reserved
25	Z	Reserved

Machine mode exception base address register (mtvec)

This register is used to store the base address of the exception or interrupt handler and the lower two bits are used to configure the mode and identification method of the vector table as described in Section 3.2.

Counter mask register (mcount_inhibit)

Bit	Name	Access	Description	Reset Value

[31:3]	Reserved	MRO	Reserved	0
2	IR	MRW	Instruction counter mask register: 1: Masks the instruction counter, and minstret and unstret stop counting. 0: Does not mask the instruction counter, and minstret and unstret count normally.	0
1	Reserved	MRO	Reserved	0
0	CY	MRW	Cycle counter mask register: 1: Masks the instruction counter, mcycle and ucycle stop counting; 0: Does not mask the cycle counter, mcycle and ucycle count normally.	0

Machine mode staging register (mscratch)

Bit	Name	Access	Description	Reset Value
[31:0]	mscratch	MRW	Data storage	0

This register is a 32-bit readable and writable register in machine mode for temporary data storage. For example, when entering an exception or interrupt handler, the user stack pointer SP is stored in this register and the interrupt stack pointer is assigned to the SP register. After exiting the exception or interrupt, restore the value of user stack pointer SP from mscratch. That is, the interrupt stack and user stack can be isolated.

Machine mode exception program pointer register (mepc)

Bit	Name	Access	Description	Reset Value
[31:0]	mepc	MRW	Exception procedure pointer	0

This register is used to save the program pointer when entering an exception or interrupt. It is used to save the instruction PC pointer before entering an exception when an exception or interrupt is generated, and mepc is used as the return address when the exception or interrupt is handled and used for exception or interrupt return. However, it is important to note that.

- When an exception occurs, mepc is updated to the PC value of the instruction currently generating the exception.
- When an interrupt occurs, mepc is updated to the PC value of the next instruction.

When you need to return an exception after processing the exception, you should pay attention to modifying the value of the mepc, and more details can be found in Chapter 2 Exceptions.

Machine mode exception cause register (mcause)

Bit	Name	Access	Description	Reset Value
31	Interrupt	MRW	Interrupt indication field 0: Exception 1: Interruption	0
[30:0]	Exception Code	MRW	Exception codes, see Table 2-1 for details	0

This register is mainly used to store the cause of the exception or the interrupt number of the interrupt. Its highest bit is the Interrupt field, which is used to indicate whether the current occurrence is an exception or an interrupt. The lower bit is the exception code, which is used to indicate the specific cause. Its details can be found in Chapter 2 Exceptions.

Machine mode exception value register (mtval)

Bit	Name	Access	Description	Reset Value
[31:0]	mtval	MRW	Exception value	0

This register is used to hold the value that caused the exception when an exception occurs. For details such as the value and time of its storage, please refer to Chapter 2 Exceptions.

PMP configuration register (pmpcfg<i>)

This register is mainly used to configure the physical memory protection unit, and every 8 bits of this register are used to configure the protection of an area. Please refer to Chapter 4 for the detailed definition.

PMP address register (pmpaddr<i>)

This register is mainly used for the address configuration of the physical memory protection unit, which encodes the upper 32 bits of a 34-bit physical address. Please refer to Chapter 4 for the specific configuration method.

Debug trigger select register (tselect)

It is only valid for microprocessors that support hardware breakpoints, and supports 4-channel breakpoints at most, and its lower 2 bits are valid. When configuring each channel breakpoint, you need to select the corresponding channel through this register before configuration.

Bit	Name	Access	Description	Reset Value
[31:2]	Reserved	MRO	Reserved	0
[1:0]	TSELECT	MRW	The breakpoint channel selection register is configured, that is, after the corresponding channel is selected, the tdata1 and tdata2 registers can be operated to configure breakpoint information.	X

Debug trigger data register 1(tdata1)

It is only valid for microprocessors that support hardware breakpoints. Microprocessors only support instruction address and data address breakpoints, where the bit TYPE of the tdata1 register is a fixed value of 2, and other bits conform to the definition of mcontrol in the debugging standard.

Bit	Name	Access	Description	Reset Value
[31:28]	TYPE	MRO	Breakpoint type definition, mcontrol type.	0x2
27	DMODE	MRO	0: The relevant registers of the flip-flop can be modified in both machine mode and debugging mode; 1: Only debug mode can modify the relevant registers of the flip-flop.	1
[26:21]	MASKMAX	MRO	When MATCH=1, the maximum exponential power range of matching is allowed, that is, the maximum allowable matching range is 2^{31} bytes.	0x1F
[20:13]	Reserved	MRO	Reserved	0
12	ACTION	MRW	Set the processing mode when triggering a breakpoint: 0: When triggering, enter the breakpoint and call	0

			back the interrupt; 1: Enter debugging mode when triggered.	
[11:8]	Reserved	MRO	Reserved	0
7	MATCH	MRW	Matching policy configuration: 0: Match when the trigger value is equal to TDATA2; 1: The trigger value matches the high m bit of TDATA2, where m = 31–n, and n is the first 0 quote of TDATA2 (starting from the low bit).	0
6	M	MRW	Enable flip-flop in M mode: 0: Disable the trigger in M mode; 1: Enable the trigger in M mode.	0
[5:4]	Reserved	MRO	Reserved	0
3	U	MRW	Enable trigger in U mode: 0: Disable the trigger in U mode; 1: Enable the trigger in U mode.	0
2	EXECUTE	MRW	Instruction read address trigger enabled: 0: Disable; 1: Enable.	0
1	STORE	MRW	Data write address trigger enabled: 0: Disable; 1: Enable.	0
0	LOAD	MRW	Data read address trigger enabled: 0: Disable; 1: Enable.	0

Debug trigger data register 2(tdata2)

It is only valid for microprocessors that support hardware breakpoints, and is used to save the matching value of the trigger.

Bit	Name	Access	Description	Reset Value
[31:0]	TDATA2	MRW	Used to save matching values.	X

Trigger information register (tinfo)

Bit	Name	Access	Description	Reset Value
[31:0]	tinfo	MRO	The trigger information register corresponds to the type value of the TDATA1 register, and the type value is 2, and the second bit of tinfo is set to 1.	0x4

Debug control and status register (dcsr)

This register is used to control and record the running state of the debugging mode. Refer to Section 7.1 for details.

Debug mode program pointer (dpc)

This register is used to store the address of the next instruction to be executed after the microprocessor enters

the debugging mode, and its value is different according to the reasons for entering the debugging mode, and the updating rules are also different. Refer to Section 7.1 for detailed description.

Debug mode staging register (dscratch0-1)

This group of registers is used for temporary storage of data in Debug mode.

Bit	Name	Access	Description	Reset Value
[31:0]	dscratch	DRW	Debug mode data staging value	0

Debug register 0 (dbgmcu_0)

Bit	Name	Access	Description	Reset Value
[31:8]	dbg_mode_stop	MRW	The registration module stops working when entering the debugging mode: 1. The registered peripheral stops working when the core enters the debugging mode; 0: The registered peripheral works normally when the core enters debugging mode.	0
[7:0]	dbg_link_stop	MRW	The registered module stops working when you enter the connected debugger: 1: The registered peripheral stops working when you connect the debugger; 0: The registered peripheral works normally when you connect the debugger.	0

Machine cycle counter register (mcycle)

CSR address: 0xB00

Bit	Name	Access	Description	Reset Value
[31:0]	mcyle	MRW	The machine cycle counter is used to count the clock cycles of the machine. It counts when the CY bit in the MCOUNT_INHIBIT register is 0, and does not count when the counter stops in debugging mode.	0

Machine instruction counter register (minstret)

CSR address: 0xB02

Bit	Name	Access	Description	Reset Value
[31:0]	minstret	MRW	The instruction counter is used to count the number of instructions correctly executed by the machine. It counts when the IR bit in the MCOUNT_INHIBIT register is 0, and it does not count when the counter stops in debugging mode.	0

User mode cycle counter register (ucycle)

Bit	Name	Access	Description	Reset Value
[31:0]	ucyle	RO	The user mode cycle counter is used to count the	0

			clock cycles of the machine. When the CY bit in the MCOUNT_INHIBIT register is 0, it does not count when the counter stops in debugging mode.	

Note: The user mode cycle counter has the same function as the mcycle register, and is used to read the number of running cycles of the machine in user mode.

Floating-point accumulation exception flag register (fflags)

Bit	Name	Access	Description	Reset Value
[31:5]	Reserved	RO	Reserved	0
[4:0]	FFlags	RW	Accumulated exception flag, used to indicate exceptions that have occurred on floating point arithmetic instructions since the last reset (reset or software clear). name / bit / description NV / 4 / Illegal operation DZ / 3 / Divide by zero OF / 2 / Overflow up UF / 1 / Overflow down NX / 0 / Imprecise	0

Floating-point rounding mode register (frm)

Bit	Name	Access	Description	Reset Value
[31:3]	Reserved	RO	Reserved	0
[2:0]	Frm	RW	Floating-point operation rounding mode register: 000: Round to the nearest value (round to the even direction when it is in the middle value); 001: Round to zero; 010: Round down; 011: Round up; 100: Rounding to the nearest value (rounding to the maximum magnitude when it is in the middle value); 101, 110: Reserved; 111: Dynamic rounding: select the rounding mode according to the configuration value of FRM bit in the instruction.	0

Floating-point control and status register (fcsr)

Bit	Name	Access	Description	Reset Value
[31:8]	Reserved	RO	Reserved	0
[7:5]	Frm	RW	Floating-point operation rounding mode	0

			register.	
[4:0]	FFlags	RW	Cumulative anomaly flag.	0

Cache policy control register (cache_strtg_ctlr)

Bit	Name	Access	Description	Reset Value
[31:28]	Reserved	RO	Reserved	0
27	ic_mem1_strtg	MRW	Enable instruction cache for the 0x80000000-0x9fffffff region: 1: Allow caching of instructions in this region; 0: Disallow caching of instructions in this region.	1
26	ic_mem0_strtg	MRW	Enable instruction cache for 0x60000000-0x7fffffff area.	1
25	ic_sram_strtg	MRW	Enable instruction cache for 0x20000000-0x3fffffff area.	1
24	ic_code_strtg	MRW	Enable instruction cache for 0x00000000-0x1fffffff area.	1
[23:2]	Reserved	RO	Reserved	0
1	ic_disable	MRW	Instruction cache disable flag bit, which is 0 to turn on the instruction cache function.	1
0	Reserved	RO	Reserved	1

Cache policy control register (cache_pmp_ovr)

Bit	Name	Access	Description	Reset Value
[31:13]	Reserved	MRO	Reserved	0
12	ic_pmp3cache_strtg	MRW	Instruction cache policy register in PMP channel 3 address area.	0
[11:9]	Reserved	MRO	Reserved	0
8	ic_pmp2cache_strtg	MRW	Instruction cache policy register in PMP channel 2 address area.	0
[7:5]	Reserved	MRO	Reserved	0
4	ic_pmp1cache_strtg	MRW	Instruction cache policy register in PMP channel 1 address area.	0
[3:1]	Reserved	MRO	Reserved	0
0	ic_pmp0cache_strtg	MRW	Instruction cache policy register for PMP channel 0 address area: 1: When the instruction address is protected by PMP channel 0, the current instruction can be cached. 0: When the instruction address is protected by PMP channel 0, the current instruction cannot be cached.	0

Note: The cache policy PMP covers the register. When the instruction or data address matches the address controlled by the PMP channel, the policy in the cache policy control register (0xBC2) is not executed, but the policy matched with the PMP channel in this register is executed.

Hardware stack address register (hw_popdm_addr)

Bit	Name	Access	Description	Reset Value
[31:20]	hw_stk_vector	MRO	Fixed header address of DTCM area.	0x200
[19:9]		MRW	DTCM area block address, 512bit alignment.	0x500
[8:0]		MRO	Fixed to 0.	0

Note: The hardware stack pressing address register points to the DTCM area. When the hardware stack pressing function is enabled and an interrupt/exception is entered, the stack value is quickly saved to the designated DTCM area, usually pointing to the bottom of the DTCM area.

Memory configuration register (memary_cfgr)

Bit	Name	Access	Description	Reset Value
[31:20]	MEM0_addr_hi	MRW	The branch predictor address matching register is configured as the high 12-bit address information of the external memory. When the high-bit address of the external memory does not match, some branch prediction functions are limited. *Note: Do not configure it as the high address of internal memory (0x000, 0x200, 0x201).*	0x600
[19:18]	dtcm_rr_mode	MRW	DTCM Memory Access Priority Mode: 00: Fixed priority, other requests (DMA, C0_lsu, C0_ifu) have higher priority than C1 requests; 01: Fixed priority, C1 requests have higher priority than other requests (DMA, C0_lsu, C0_ifu); 10: Polling priority, where a channel can obtain operation priority for a continuous period of time, after which it switches to another channel. If the channel with priority has no operation requests while the other channel has requests, the priority switches to the other channel and the timer resets. The priority duration is configured in the TCM_RRDUTY_CFGR register. 11: Forced polling priority, where a channel is forced to obtain operation priority for a certain period of time. After the timeout, it switches to another channel. The priority duration configuration is specified in the TCM_RRDUTY_CFGR register.	0x3
[17:16]	itcm_rr_mode	MRW	ITCM Memory Access Priority Mode: 00: Fixed priority, other requests (DMA, C0_lsu, C0_ifu) take precedence over C1 requests 01: Fixed priority, C1 requests take precedence over other requests (DMA, C0_lsu, C0_ifu) 10: Polling priority, where a channel can obtain operation priority for a continuous period of time. After the timeout, it switches to another channel. If the channel with priority has no operation requests while the other channel has requests, the priority switches to	0x3

			the other channel and the timer resets. The priority duration is configured in the TCM_RRDUTY_CFGR register. 11: Forced polling priority: A channel is forced to obtain operation priority for a certain period of time. After the timeout, it switches to another channel. The priority duration configuration is specified in the TCM_RRDUTY_CFGR register.	
[15:12]	Reserved	RO	Reserved	0
[11:10]	C0_ifu_dtcm_mode	MRW	C0_IFU DTCM memory access permission configuration: C0_ifu_dtcm_mode[1]: 1: Read enabled; 0: Read disabled. C0_ifu_dtcm_mode[0]: 1: Write enabled; 0: Write disabled.	0x3
[9:8]	C0_ifu_itcm_mode	MRW	C0_IFU ITCM memory access permission configuration: C0_ifu_itcm_mode[1]: 1: Read enabled; 0: Read disabled. C0_ifu_itcm_mode[0]: 1: Write enabled; 0: Write disabled.	0x3
[7:6]	C0_lsu_dtcm_mode	MRW	C0_LSU DTCM memory access permission configuration: C0_lsu_dtcm_mode[1]: 1: Read enabled; 0: Read disabled. C0_lsu_dtcm_mode[0]: 1: Write enabled; 0: Write disabled.	0x3
[5:4]	C0_lsu_itcm_mode	MRW	C0_LSU ITCM memory access permission configuration: C0_lsu_itcm_mode[1]: 1: Read enabled; 0: Read disabled. C0_lsu_itcm_mode[0]: 1: Write enabled; 0: Write disabled.	0x3
[3:2]	DMA_dtcm_mode	MRW	DMA to DTCM memory access permission configuration: DMA_dtcm_mode[1]: 1: Read enabled; 0: Read disabled.	0x3

			DMA_dtcm_mode[0]: 1: Write enabled; 0: Write disabled.	
[1:0]	DMA_itcm_mode	MRW	DMA configuration for ITCM memory access permissions: DMA_itcm_mode[1]: 1: Read enabled; 0: Read disabled. DMA_itcm_mode[0]: 1: Write enabled; 0: Write disabled.	0x3

TCM priority access duration configuration register (tcm_rrduty_cfgr)

Bit	Name	Access	Description	Reset Value
[31:24]	C1_dtcm_rr_cycle	MRW	A persistent clock cycle configuration with high priority is requested for dtcm from C1.	0
[23:16]	Cx_dtcm_rr_cycle	MRW	A non-C1(C0, dma) requests a high-priority persistent clock cycle configuration for dtcm.	0
[15:8]	C1_itcm_rr_cycle	MRW	A continuous clock cycle configuration with high priority is requested from C1 for itcm.	0
[7:0]	Cx_itcm_rr_cycle	MRW	A non-C1(C0, dma) requests a high-priority persistent clock cycle configuration for itcm.	0

Note: TCM regional access priority duration configuration takes effect when itcm_rr_mode and dtcm_rr_mode in TCM_CFGR are configured as 10b or 11b, which is used to control the duration of high priority of corresponding channel.

Machine interrupt register (mie)

Bit	Name	Access	Description	Reset Value
[31:9]	Reserved	RO	Reserved	0
[8:0]	nest_mie	RW	Machine interrupt register, storing mie information for each level of interrupt in a multi-level interrupt nesting: MSTATUS register mie bit = nest_mie[0]; MSTATUS register mpie bit = nest_mie[1].	0

Cache operation register (opcache_ctlr)

Bit	Name	Access	Description	Reset Value
[31:5]	Vaddr	WO	Operation address or index information.	0
2	Idx_mode	WO	Index mode 1: Perform operations using the vaddr value as address information. 0: Perform operations using the index information in the vaddr value as the starting address.	0
[1:0]	Opcode	WO	00：Icache invalidate； Others: Invalid.	0

Cache operation register (meminfo)

Bit	Name	Access	Description	Reset Value
[31:30]	Reserved	RO	Reserved	0
[29:26]	DTCM datasize	MRO	Data memory capacity information: $64KB*2^{DTCM\ datasize}=256KB$	0100b
[25:24]	DTCM LineSize	MRO	Data memory row length information: 00: 8 bytes; 01: 16 bytes; 10: 32 bytes; 11: 64 bytes.	10b
[23:22]	Reserved	RO	Reserved	0
[21:18]	ITCM datasize	MRO	Instruction memory capacity information: $64KB*2^{ITCM\ datasize}=128KB$	0010b
[17:16]	ITCM LineSize	MRO	Instruction memory row length information: 00: 8 bytes; 01: 16 bytes; 10: 32 bytes; 11: 64 bytes.	10b
[15:7]	Reserved	RO	Reserved	0
[6:5]	Icache_way	MRO	Number of instruction cache ways: 00: 1-way; 01: 2-way; 10: 4-way; 11: 8-way.	01b
[4:2]	Icache_datasize	MRO	Instruction cache capacity information: 000: NONE; 001: 4KB; 010: 8KB; 011: 16KB; 100: 32KB; 101: 64KB; 110: 128KB; 111: 256KB.	100b
[1:0]	Icache linesize	MRO	instruction cache line length information: 00: 8byte; 01: 16byte; 10: 32byte; 11: 64byte.	0

8.3 User-defined CSR Register

User mode global interrupt enable register (gintenr)

This register is used to control the enable and mask of global interrupt. The enable and mask of global interrupt in machine mode can be controlled by the MIE and MPIE bits in mstatus, but this register cannot be operated in user mode. While the global interrupt enable register gintenr is the mapping of MIE and MPIE in mstatus.

In user mode, gintenr can be used to set and clear MIE and MPIE, as described in Section 3.2 for details.

Note: Global interrupts do not include unmasked interrupts NMI and exceptions.

Interrupt system control register (intsyscr)

This register is mainly used to configure interrupt nesting depth, hardware stack pressing and other related functions, as described in Section 3.2 for details.

Microprocessor configuration register (corecfgr)

This register is used to control whether the NMI interrupt is allowed after the interrupt overflows, and whether the interrupt request is cleared when the fence instruction is executed. Please refer to Section 3.2 for the specific definition.

Interrupt nested control register (inestcr)

This register is used to indicate the interrupt nesting state and whether it overflows or not, and to control the maximum nesting level. Please refer to Section 3.2 for the specific definition.